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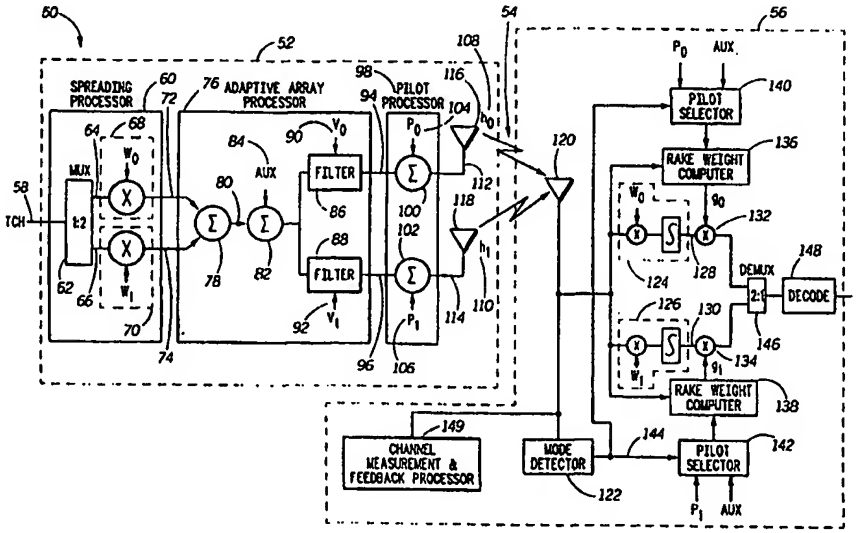

(57) Abstract

In a method for producing antenna element signals (112 and 114) for transmitting a serial traffic channel (58) from a plurality of elements (116 and 118) in an antenna array, data in the serial traffic channel is converted to data in two or more parallel traffic channels (64 and 66). Thereafter, data in the two or more parallel traffic channels are spread with different spreading codes (68 and 70) to produce spread traffic signals (72 and 74). The spread traffic signals are combined to produce combined signals (80), which are each modified according to adaptive array weigths (90 and 92) to produce element signals (94 and 96). A pilot signal is then added (98) to at least one of the element signals to produce two or more antenna element signals (94 and 96).

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METHOD AND SYSTEM FOR COMBINING ORTHOGONAL TRANSMIT DIVERSITY AND ADAPTIVE ARRAY TECHNIQUES IN A WIRELESS COMMUNICATIONS SYSTEM

Field of the Invention

The present invention relates generally to wireless communication systems, and more particularly to wireless communication systems using adaptive antenna arrays.

Background of the Invention

Recently, wireless communication systems owners and operators have asked communication system designers to increase the capacity of wireless communication systems. This capacity, or the ability to carry user data, is what the operators sell to the system users. Therefore, increased capacity means increased profitability for communication system operators.

One method of improving capacity is to reduce the amount of energy needed to transmit a bit of information over the wireless air interface. Several methods of reducing the energy per bit have been proposed. Two of these proposals include transmitting user data using adaptive antenna arrays, and transmitting data using a method of transmission known as "orthogonal transmit diversity."

Transmitting user data with adaptive antenna arrays is a technique implemented by measuring the channel characteristics and modifying the gain and phase of signals applied to each element in an antenna array in order to create an antenna pattern that maximizes the power delivered to the subscriber unit. One of the disadvantages of adaptive array technology is the need for constant measurement and feedback of the channel characteristics and the subsequent recalculation of the adaptive array weights used to modify signals for each antenna element. The time needed to measure and compute the weights limits the speed at which the antenna pattern may be modified to compensate for a changing channel. Thus, when the subscriber travels at a higher speed, the channel changes at a rate higher than the rate of compensation in the adaptive antenna array. Thus, the feedback loop in the adaptive array technique cannot keep up with a quickly changing channel between the base station antenna and a higher-speed subscriber unit.

With regard to orthogonal transmit diversity, it is implemented by first converting a serial traffic channel into two or more parallel traffic channels using a multiplexer. If the traffic channel is converted into two parallel traffic channels, the

two parallel traffic channels operate at one half the rate of the serial traffic channel input into the multiplexer.

Once the data is multiplexed, each parallel traffic channel is spread with a different spreading code to produce two or more spread traffic signals. These two spread traffic signals are then added together and transmitted from either a single antenna or separately transmitted from two or more separate antennas.

Some designers have proposed a communication system that switches from adaptive antenna transmission to orthogonal transmit diversity when the feedback required in adaptive antenna transmission begins to fail. A first problem with this mode switching proposal is that the receiver must be able to operate in two modes, where the adaptive array mode demodulates with one despreading code, and the orthogonal diversity mode demodulates with multiple codes despreading. Operating in two modes requires additional complexity in the receiver.

Because it is desirable to use a single receiver structure, it has been proposed that radio systems having orthogonal transmit diversity capabilities always transmit with multiple codes, even when transmit diversity is not active. Presently known transmitters using adaptive arrays presume that a single code spreads the transmitted data, which is a mode incompatible with the orthogonal transmit diversity proposal.

Another problem with the mode switching proposal is that the base station is required to send a message which tells the mobile which mode to use. Such messaging is slow in switching modes and requires additional mobile station circuitry or programming to implement.

Therefore, it should be apparent that there is a need for an improved method and system of transmitting and receiving a traffic channel using techniques from both orthogonal transmit diversity and adaptive antenna array transmission.

Brief Description of the Drawings

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objects, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 depicts a wireless communications system in accordance with the method and system of the present invention;

FIG. 2 a high-level flowchart illustrating the process of producing antenna element signals in accordance with the method and system of the present invention;

FIG. 3 is depicted a high-level flowchart illustrating the process of demodulating a signal in a subscriber unit wherein the signal has been transmitted according to the present invention;

FIG. 4 depicts an alternate embodiment of an adaptive array processor in **FIG. 1** in accordance with the method and system of the present invention;

FIG. 5 depicts yet another alternate embodiment of an adaptive array processor in accordance with the method and system of the present invention;

FIG. 6 depicts yet another embodiment of an adaptive array processor in accordance with the method and system of the present invention; and

FIG. 7 there is depicts still another embodiment of an adaptive array processor in accordance with the method and system of the present invention.

Detailed Description of the Invention

With reference now to **FIG. 1**, there is depicted wireless communications system **50**, which may be used to implement one embodiment of the method and system of the present invention. Wireless communication system **50** includes base transmitter **52**, which transmits signals via communication channel **54** to subscriber unit **56**. Note that **FIG. 1** shows only the downlink of a communications system that may also include an uplink for duplex operation. An uplink may also be required for providing a feedback loop for data and commands for operating the downlink in an adaptive array mode.

Base transmitter **52** includes traffic channel **58**, which is typically a serial data stream source of user data. Such data may represent voice signals or other user data, such as software, documents, images, facsimile data, or the like.

As shown, traffic channel **58** is coupled to spreading processor **60**. Spreading processor **60** includes multiplexer **62**, which is used to convert traffic channel **58** into two or more parallel traffic channels operating at a data rate that is inversely proportional to the number of traffic channels created by multiplexer **62**. For example, as shown in **FIG. 1**, multiplexer **62** converts traffic channel **58** into two parallel traffic channels **64** and **66**, each of which operates at one half the data rate of traffic channel **58**, the input to multiplexer **62**.

Parallel traffic channels **64** and **66** output by multiplexer **62** are coupled to spreaders **68** and **70**, which spread the parallel traffic channels using spreading codes W_0 and W_1, as shown. The outputs of spreading processor **60** are spread traffic signals **72** and **74**.

Spread traffic signals **72** and **74** are coupled to adaptive array processor **76**, wherein, in the embodiment shown, they are added together by summer **78** to produce combined signal **80**.

Combined signal **80** is coupled to the input of summer **82** for adding auxiliary pilot **84** to combined signal **80**. Auxiliary pilot **84** is added so that subscriber unit **56** may use it as a reference for demodulating the received signal.

The output of summer **82** is split and coupled to filters **86** and **88**, which filter the signal according to adaptive array weights **90** and **92** to produce element signals **94** and **96**. Filters **86** and **88** may be implemented with a zero-delay, single-tap digital filter, which is equivalent to a complex multiplier.

Element signals **94** and **96** are coupled to pilot processor **98**, which adds one or more pilot signals to element signals **94** and **96**. As shown, summers **100** and **102** add element pilot signals **104** and **106**, respectively, to element signals **94** and **96**. Element pilot signals **104** and **106** are used by subscriber unit **56** to estimate or measure channel characteristics of communication channel **54**. Such channel characteristics are shown as channel impulse responses h_0, **108** and h_1, **110**.

The output of summers **100** and **102** are antenna element signals **112** and **114**. These signals are modulated and amplified and coupled to antenna elements **116** and **118** of an antenna array.

With reference now to subscriber unit **56**, subscriber antenna **120** receives signals from antenna elements **116** and **118**. Although not shown in **FIG. 1**, signals received by subscriber antenna **120** are down converted and coupled to mode detector **122** and despreaders **124** and **126**. Despreaders **124** and **126** despread the received signal by multiplying the signal by spreading codes W_0 and W_1, wherein both multipliers are followed by an integration operation, as shown. Despread signals **128** and **130**, which are output from despreaders **124** and **126**, are coupled to multipliers **132** and **134**. Multipliers **132** and **134** multiply despread signals **128** and **130** by RAKE weight g_0 and g_1, respectively.

RAKE weights g_0 and g_1 are computed by RAKE weight computers **136** and **138**. RAKE weight computation may be implemented by calculating the complex conjugate of the channel impulse response. When the adaptive array mode is enabled, mode detector **122** sends a signal to pilot selectors **140** and **142** to select the auxiliary pilot for RAKE weight computers **136** and **138**. The RAKE weight computers then use the auxiliary pilot to calculate the complex conjugate of the composite channel between each element **116** and **118** and the subscriber's antenna

120. This composite channel response includes impulse responses h_0 and h_1, as shown at reference numerals **108** and **110**.

If the adaptive array mode in base transmitter **52** is not enabled, RAKE weight computers **136** and **138** use pilots P_0 and P_1 selected by pilot selectors **140** and **142** in order to compute complex conjugate impulse responses of individual channels from elements **116** and **118**, as indicated by h_0 and h_1.

The reason for selecting different pilots for different modes of operation is that the auxiliary pilot is present in the signal from both antennas **116** and **118** while the element pilots, P_0 and P_1, are only present on one of the antenna elements **116** and **118**.

When mode detector **122** detects that base transmitter **52** has enabled an adaptive array mode, mode detector **122** causes pilot selector **140** and **142** to select the auxiliary pilot as a reference for RAKE weight computers **136** and **138**. When mode detector **122** detects that the adaptive array mode is not enabled, mode detector signal **144** causes pilot selectors **140** and **142** to select element pilots P_0 and P_1 as the references provided to RAKE weight computers **136** and **138**.

Output from multipliers **132** and **134** are coupled to demultiplexer **146**. As shown in **FIG. 1**, demultiplexer **146** receives two inputs and produces a single output.

In order to support an adaptive array mode in base transmitter **52**, subscriber unit **56** includes channel measurement and feedback processor **149**. Channel measurement and feedback processor **149** measures the characteristics of channels **108** and **110**, which together may be referred to as a composite channel between base transmitter **52** and subscriber unit **56**, and then appropriately formats messages to send back to a base receiver. The information contained in such messages are used to determine the operations performed in filters **86** and **88**, which may include calculating the values of V_0 and V_1.

The output of demultiplexer **146** is coupled to decoder **148**, which decodes the data that was originally transmitted from traffic channel **58**.

With reference now to **FIG. 2**, there is depicted a high-level flowchart that illustrates the process of producing antenna element signals for transmitting a traffic channel from a plurality of elements in an antenna array in accordance with the present invention. As illustrated, the process begins at block **200**, and thereafter passes to block **202** wherein the process converts a serial traffic channel data into multiple parallel traffic channel data. This process may be implemented using a

multiplexer, such as multiplexer **62** shown in **FIG. 1**. Note that the data rate of the parallel traffic channel data will be the data rate of the serial traffic channel data divided by the number of multiple parallel traffic channels. Thus, the multiple parallel traffic channel data is at most half the rate of the serial traffic channel data.

Next, the process spreads each parallel traffic channel data with a spreading code, as illustrated at block **204**. This spreading operation may be implemented as shown in **FIG. 1** with spreaders **68** and **70**. In a preferred embodiment, the spreaders use unique spreading codes, or spreading codes that are distinct from one another. Furthermore, these spreading codes are orthogonal sequences which allow the spread data to be recovered in a receiver.

Next, the process determines whether or not an adaptive array mode is enabled, as depicted at block **206**. Preferably the adaptive array mode is enabled when reliable feedback is available from the subscriber unit, and when the antenna adaptation rate is fast enough to adapt to the rate at which the channel changes.

If the adaptive array mode is enabled, the process of the embodiment shown then combines a user pilot, which may be called an auxiliary pilot, and each parallel traffic channel data to produce combined signals, as illustrated at block **208**. In one of the simplest embodiments of the present invention, the combined signals are produced by splitting the output signal of a summer, wherein the summer adds all the parallel traffic channel data and the auxiliary pilot. Example of such summers are summers **78** and **82** in **FIG. 1**. In other more complicated embodiments of the present invention, the combining may be implemented by appropriately weighting the parallel traffic channel data and adding the weighted data as shown and described in relation to **FIGs. 5, 6,** and **7**. Such weighting and adding steps may be implemented with matrix multiplication. (See **FIG. 7** and related description.)

Although the process shown in **FIG. 2** combines a user or auxiliary pilot signal in block **208**, some embodiments of the present invention may not require such an auxiliary pilot signal. Embodiments of communications systems that do not combine an auxiliary pilot signal may synthesize a pilot signal in the receiver in the subscriber unit in order to provide a reference for signal demodulation. For further information describing pilot signal synthesis in a subscriber unit see United States Patent Application Serial No. 09/107,106; filed: June 30, 1998; entitled: "Method and System for Transmitting and Demodulating a Communications Signal Using an Adaptive Antenna Array in a Wireless Communication System", which is incorporated herein by reference.

Next, in the embodiment shown, the process filters the combined signals according to adaptive array weights to produce element signals, as depicted at block

210. This step of filtering may be implemented with a digital filter, which is some cases may be a one-tap, zero-delay filter, which is equivalent to a multiplier. The adaptive array weights used by the filters are derived from measurements or estimations of the channel impulse responses of channels from each element of the antenna array at the base to the subscriber antenna. These array weights may be calculated as described in the above-identified referenced United States Patent Application Serial No. 09/107,106; filed: June 30, 1998; entitled: "Method and System for Transmitting and Demodulating a Communications Signal Using an Adaptive Antenna Array in a Wireless Communication System."

After the combined signals have been filtered, the process adds an element pilot signal to each element signal to produce antenna element signals, as illustrated at block 212. Each element pilot signal is different from every other element pilot signal so that the channels can be identified from the perspective of the subscriber unit. The subscriber unit may measure these element pilot signals to determine the channel impulse responses of the channels between antenna elements and the subscriber's antenna.

After adding the pilot signal, the process transmits the antenna element signals by modulating and amplifying the signals, and coupling such signals to corresponding antenna elements in the antenna array, as depicted at block 214.

Referring again to block 206, if the adaptive antenna array mode is not enabled, the process adds element pilots to each spread parallel traffic channel to produce antenna element signals, as illustrated at block 216. Thereafter, the process transmits the antenna element signals as shown at block 214.

Although the process is shown terminating at block 218, the process is preferably repeated for each group of bits input to base transmitter 52 from traffic channel 58. Thus, the process should be understood as a continuous process implemented in base transmitter 52, wherein traffic channel data is continuously received into the transmitter along with measurements and calculations needed to compute adaptive array weights 90 and 92 in adaptive array processor 76, as shown in FIG. 1.

With reference now to FIG. 3, there is depicted a high-level flowchart illustrating the process of demodulating a signal in a subscriber unit wherein the signal has been transmitted according to the present invention. As illustrated, the process begins at block 300 and thereafter passes to block 302 wherein the process determines whether or not the adaptive array mode is enabled. The process may determine whether or not the adaptive array mode is enabled by several techniques,

some of which are discussed below. In the system shown in **FIG. 1**, mode detector **122** makes this determination.

If the adaptive array mode is enabled, the process then selects the auxiliary pilot for a demodulation reference to be used in the demodulator in the subscriber unit, as illustrated at block **304**. The auxiliary pilot may be generated by known methods of producing a sequence of coefficients, where such sequence is specified by a message or other signaling from base transmitter **52**.

If the adaptive array mode is not enabled, the process selects the elements pilots for demodulation references in the subscriber unit, as depicted at block **306**. The element pilots may be generated in a manner similar to the generation of the auxiliary pilot. The element pilots are known sequences which are specified by a message or other signal from base transmitter **52**.

The steps depicted at blocks **302-306** may be implemented as shown in **FIG. 1** with mode detector **122** coupled to pilot selectors **140** and **142**.

After a demodulation reference or references have been selected, the process computes RAKE weights using the selected demodulation reference or references, as illustrated at block **308**. RAKE weights are typically the complex conjugate of the coefficients of the channel impulse response with the greatest magnitude.

In **FIG. 3**, blocks **302-308** depict a process of computing RAKE weights which may be executed in parallel with the steps of decoding the signal, which are shown at blocks **310-316**.

Turning now to the decoding steps, the process begins by despreading the received signal using two or more despreading codes, as depicted at block **310**. The number of despreading codes used is the same as the number of spreading codes used in spreading processor **60** in **FIG. 1**. Also shown in **FIG. 1** are despreaders **124** and **126** which may be used to implement this despreading step.

The despread signals are weighted and combined using the computed RAKE weights, as illustrated at block **312**. The RAKE weights are computed as shown and described at block **308**. This weighting and combining step compensates for the effects of the communication channel **54**, through which the received signal has passed.

Next, the process demultiplexes the signals, as depicted at block **314**. This demultiplexing step takes two or more data inputs and combines them into a single serial output. In **FIG. 1**, this process may be implemented with demultiplexer **146**, which receives two inputs and combines them into a single output. This process may be thought of as the opposite of the process of multiplexing in base transmitter **52**, as shown at block **202** in **FIG. 2**, and implemented with multiplexer **62** in **FIG. 1**.

The demultiplexed signal is then decoded, as illustrated at block **316**. The decoding process may be implemented with commonly used error correcting code decoders, including a soft decision Viterbi decoder.

The process of decoding a received signal according to the present invention is terminated at block **318**. However, the process shown in **FIG. 3** is designed to be a continuous process of receiving, despreading, weighting, demultiplexing, and decoding signals from base transmitter **52**.

With reference now to **FIG. 4**, there is depicted an alternate embodiment of adaptive array processor **76** in **FIG. 1**. Adaptive array processor **150** shown in **FIG. 4** may be used in place of adaptive array processor **76** in **FIG. 1**. As shown, spread traffic signals **72** and **74** are input into adaptive array processor **150**. Control signal **152** indicates whether or not the adaptive array mode is enabled in base transmitter **52**. When the adaptive array mode is not enabled, switches **154** and **156** are in the upper position to send spread traffic signals **72** and **74** to the outputs of adaptive array processor **150**.

If the adaptive array mode is enabled in transmitter **52**, switches **154** and **156** are in the lower position to couple spread traffic signals **72** and **74** to summer **158**, which adds the signals together. The output of summer **158** is coupled to summer **160** wherein an auxiliary pilot may be added to the combined signals from summer **158**.

The output of summer **160** is then split and filtered by filters **162** and **164** in a manner similar to that described with reference to filters **86** and **88** in **FIG. 1**.

Finally, the output of filters **162** and **164** are output from adaptive array processor **150** as element signals **94** and **96**. Thus, adaptive array processor **150** operates the same way as adaptive array processor **76** except that the adaptive array processing may be enabled and disabled by control signal **152**. When adaptive array processor **150** is disabled, base transmitter **52** operates in an orthogonal transmit diversity mode.

With reference now to **FIG. 5**, there is depicted yet another alternate embodiment of adaptive array processor **76**. As illustrated, adaptive array processor **166** receives spread traffic signals **72** and **74** as inputs to summers **168** and **170**. Summers **168** and **170** add auxiliary pilots AUX_0 and AUX_1 to spread traffic signals **72** and **74**. Pilots AUX_0 and AUX_1 are different because spread traffic signals **72** and **74** are not combined by simply summing the two signals together as shown in **FIGs. 1** and **4**—in this embodiment of adaptive array processor **166**, spread traffic signals **72** and **74** are combined by adding a portion of the signal in one path to the

signal in the other path. This portion is determined by the coefficient α in **FIG. 5**. Thus, multipliers **172** and **174** divide the signal power output by summer **168**, wherein a portion of the signal power proceeds on a path through adaptive array processor **166** to become element signal **94**, and another portion of the signal power output by summer **168** proceeds along a path toward element signal **96**. Stated another way, the fraction of the signal power going to each output of adaptive array processor **166** is determined by the value of α, wherein α varies from 0 to the reciprocal of the square root of 2.

Similarly, multipliers **176** and **178** divide the signal power output by summer **170** between the branches of adaptive array processor **166** that produce element signals **94** and **96**.

Multipliers **180** and **182**, which are simple implementations of filters, are used to modify the combined signals according to adaptive array weights to produce element signals **94** and **96**. These filters operate similar to filters **86** and **88** in **FIG. 1**. As shown, these filters are zero delay, single tap filters.

It should be noted that when the value of α is equal to 0, and adaptive array weights V_0 and V_1 at multipliers **180** and **182** are equal to 1, adaptive array processor **166** is figured so that base transmitter **52** operates in an orthogonal transmit diversity mode. In this case, adaptive array processor **166** behaves as though switches **154** and **156** in adaptive array processor **150** in **FIG. 4** have been set to the upper position to pass traffic signals **72** and **74** directly through to the outputs of element signals **94** and **96**.

If α is set equal to the reciprocal of the square root of 2, and calculated adaptive array weights V_0 and V_1 are used in multipliers **180** and **182**, adaptive array processor **166** is configured so that base transmitter **52** operates in an adaptive array mode. In this configuration, adaptive array processor **166** behaves like adaptive array processor **150** with switches **154** and **156** set in the lower position to couple spread traffic signals **72** and **74** through summer **158** and filters **162** and **164**.

If α is set to a value between 0 and the reciprocal of the square root of 2, adaptive array processor **166** is configured so that base transmitter **52** operates in a mixed mode—a mode that is not strictly an orthogonal transmit diversity mode nor an adaptive array mode. In this mixed mode base transmitter **52** exhibits characteristics of both modes. If the value of α is allowed to vary between its extremes, base transmitter **52** may smoothly transition between orthogonal transmit diversity mode and adaptive array mode. This smooth transition may allow base

transmitter **52** to slowly disable the adaptive array mode in proportion to the degradation of the quality of the feedback data, which typically degrades as the speed of the subscriber unit increases.

Because adding auxiliary pilots such as a AUX_0 and AUX_1 consumes power that might otherwise be used to transfer user data, not adding AUX_0 and AUX_1 in adaptive array processor **166** is a desirable goal. However, AUX_0 and AUX_1 are added because they provide a demodulation reference in subscriber unit **56**. Without this demodulation reference, the subscriber unit must know adaptive array weights V_0 and V_1 in order to properly demodulate the received signal. Therefore, if AUX_0 and AUX_1 are not used, subscriber unit **56** must be able to calculate adaptive array weights V_0 and V_1, which may be accomplished mathematically by analyzing the joint statistical characteristics of the signals output by despreaders **124** and **126** in combination with the knowledge of the value of α, which describes how spread traffic signals **72** and **74** are combined.

With reference now to **FIG. 6**, there is depicted yet another embodiment of adaptive array processor **76**. As shown, adaptive array processor **230** includes n+1 inputs, in contrast with the two inputs of adaptive array processors **76**, **150** and **166**. Within adaptive array processor **230** power is split in equal portions from each of the n paths, and each split portion is added to another one of the n paths. The value of α sets the ratio of power in bits in other paths that are combined with the power of the bit input to a particular path. The portions of energy split or diverted from an input path and combined with another path are all equal.

The values of α in adaptive array processor **230** range from zero to the reciprocal of the square root of n+1, as depicted in the range shown in **FIG. 6**. When α is equal to zero, adaptive array processor is configured so that base transmitter **52** operates in an orthogonal transmit diversity mode. When α is set equal to the reciprocal of the square root of n+1, adaptive array processor **230** is configured so that base transmitter **52** operates in an adaptive array mode. Therefore, when the value of α is at either extreme, adaptive array processor **230** operates similar to an n+1—input version of adaptive array processor **150**, which may be switched between modes.

With reference now to **FIG. 7**, there is depicted still another embodiment of adaptive array processor **76**. As depicted, adaptive array processor **250** includes n+1

inputs for receiving spread traffic signals b_0-b_n. The difference between adaptive array processor **250** in **FIG. 7** and adaptive array processor **230** in **FIG. 6** is the ability of adaptive array processor **250** to split unequal portions of signal power to combine with other signal paths in the adaptive array processor. In adaptive array processor **230** in **FIG. 6** the portions of energy split or diverted from an input path and combined with another path are all equal.

When adaptive array processor is set in an orthogonal transmit diversity mode, base transmitter **52** transmits a uniform level of power over an entire sector or antenna coverage area. When adaptive array mode is enabled, adaptive array processor **230** and base transmitter **52** transmit power unevenly over the sector, ideally with the maximum power being delivered to the subscriber unit.

Because the energy split or diverted from one path for combining with another selected path in adaptive array processor **250** may be independently selected, and because the phase at which various paths are combined may be individually selected, base transmitter **52** can transmit different spread bits with different codes in different amounts of power across different directions in a sector. This mode of operation is a further generalization of orthogonal transmit diversity and adaptive antenna transmission.

Note that as the number of paths or branches in adaptive array processor **76** increases above two paths, modification must be made in spreading processor **60**, pilot processor **98**, and subscriber unit **56**. In spreading processor **60**, multiplexer **62** must output n+1 branches or paths. Additional spreaders such as **68** and **70** must be added for each path. With regard to pilot processor **98**, additional summers such as **100** and **102** may be needed for each path, along with new element pilot signals, such as element pilot signals **104** and **106**. Additional antenna elements **116** and **118** may also be needed.

In subscriber unit **56**, additional demodulation paths may be needed, wherein such paths include despreaders **124** and **126** and multipliers **132** and **134**. Demultiplexer **146** must be able to demultiplex n+1 inputs.

Also note that in the embodiment in **FIG. 1**, the number of spread traffic signals **72** and **74** may or may not be equal to the number of element signals **94** and **96**. For example, the number of spreading codes used need not be equal to the number of elements used in the antenna array.

With regard to mode detector **122** in **FIG. 1**, several methods may be used to detect whether or not the transmitter is transmitting in an adaptive array mode or not. One simply method includes sending a message from base transmitter **52** to subscriber unit **56**. Another method that may be used is the detection of auxiliary

pilot **84**. For example, if the embodiment shown in **FIG. 4** is used, adaptive array processor **150** adds an auxiliary pilot to element signals **94** and **96** when control signal **152** places switches **154** and **156** in the lower position to enable the adaptive array mode. When control signal **152** sets switches **154** and **156** to the upper position, an auxiliary pilot signal is not present in element signals **94** and **96**. This would indicate to subscriber unit **56** that transmitter **52** is operating in the orthogonal transmit diversity mode.

The foregoing description of a preferred embodiment of the invention has been presented for the purpose of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The embodiment was chosen and described to provide the best illustration of the principles of the invention and its practical application, and to enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

Claims

What is claimed is:

1. A method for producing antenna element signals for transmitting a serial traffic channel from a plurality of elements in an antenna array, the method comprising the steps of:

converting data in the serial traffic channel to data in two or more parallel traffic channels;

spreading data in the two or more parallel traffic channels with a spreading code to produce spread traffic signals;

combining the spread traffic signals to produce combined signals;

modifying each of the combined signals according to adaptive array weights to produce element signals; and

adding a pilot signal to at least one of the element signals to produce two or more antenna element signals.

2. The method for producing antenna element signals according to claim 1 wherein the step of spreading data further includes spreading data in each of the two or more parallel traffic channels with unique spreading codes to produce spread traffic signals.

3. The method for producing antenna element signals according to claim 1 wherein the step of combining the spread traffic signals to produce combined signals further includes the steps of:

weighting the spread traffic signals to produce weighted spread traffic signals; and

adding the weighted spread traffic signals to produce a plurality of combined signals.

4. The method for producing antenna element signals according to claim 1 wherein the step of combining the spread traffic signals to produce combined signals further includes the steps of:

adding the spread traffic signals to produce an added signal; and

splitting the added signal to produce a plurality of combined signals.

5. The method for producing antenna element signals according to claim 1 wherein the combined signals are substantially the same signal.

6. The method for producing antenna element signals according to claim 1 wherein the step of modifying each of the combined signals according to adaptive array weights to produce element signals further includes filtering each of the combined signals according to adaptive array weights to produce element signals.

7. The method for producing antenna element signals according to claim 1 wherein the step of adding a pilot signal to at least one of the element signals to produce two or more antenna element signals further includes adding an element pilot signal to each of the element signals to produce two or more antenna element signals, wherein all element pilot signals are different from every other element pilot signal.

8. The method for producing antenna element signals according to claim 1 wherein the step of modifying each of the combined signals according to adaptive array weights to produce element signals further includes modifying each of the combined signals according to adaptive array weights to produce element signals, wherein the adaptive array weights are derived from measurements of channel characteristics of a channel between the antenna array and a subscriber antenna.

9. The method for producing antenna element signals according to claim 1 wherein the step of combining the spread traffic signals to produce combined signals further includes the step of combining the spread traffic signals and an auxiliary pilot to produce combined signals.

10. A wireless communication system comprising:

an adaptive array transmitter comprising:

a spreading processor for multiplexing and spreading traffic channel data with multiple spreading codes to produce a plurality of spread traffic signals;

an adaptive array processor for combining the plurality of spread traffic signals in selected ratios to produce a plurality of combined signals, and weighting the plurality of combined signals according to adaptive array weights to produce a plurality of element signals; and

a pilot processor for adding element pilots to each element signal; and

a receiver comprising:

a plurality of despreaders for despreading with multiple despreading codes corresponding to the multiple spreading codes in the transmitter;

a plurality of demodulators for demodulating outputs of the plurality of despreaders;

a demultiplexer for demultiplexing the outputs of the plurality of demodulators; and

a decoder for decoding the output of the multiplexer to produce received traffic channel data.

11. A receiver in a wireless communication system, wherein the wireless communication system includes a transmitter that spreads data with multiple spreading codes, the receiver comprising:

a plurality of despreaders for despreading with multiple despreading codes corresponding to the multiple spreading codes in the transmitter;

a plurality of demodulators for demodulating outputs of the plurality of despreaders;

a demultiplexer for demultiplexing the outputs of the plurality of demodulators; and

a decoder for decoding the output of the multiplexer to produce received traffic channel data.

12. The receiver according to claim 11 further comprising:

a pilot selector for selecting, in response to a control signal, a reference signal for use in the plurality of demodulators; and

a mode detector for producing the control signal, the control signal being responsive to the transmitter transmitting in one of an orthogonal transmit diversity mode and an adaptive array mode.

13. The receiver according to claim 12 wherein the mode detector further comprises an auxiliary pilot detector.

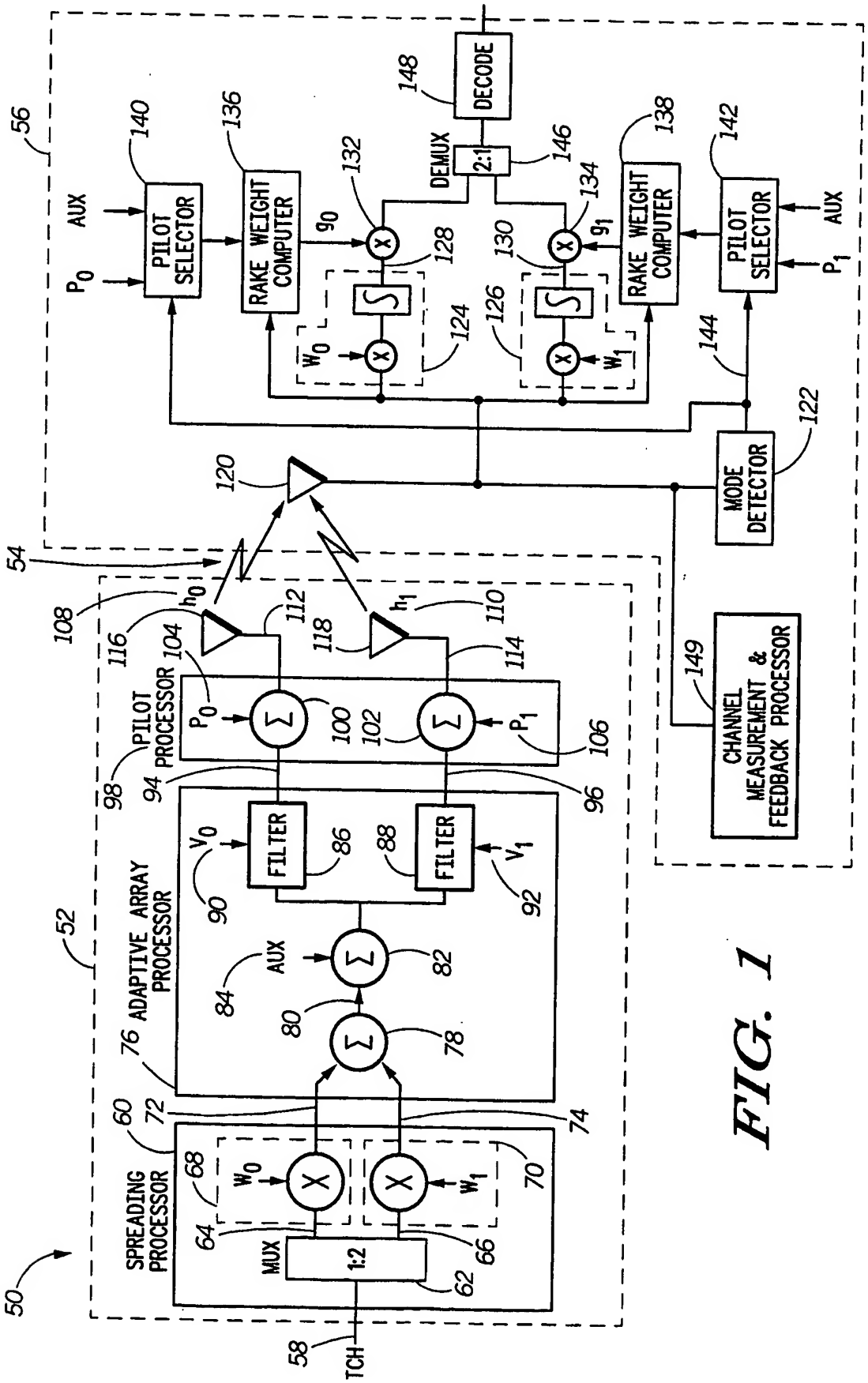

50
52
54
56
58
TCH
SPREADING PROCESSOR
MUX
1:2
ADAPTIVE ARRAY PROCESSOR
FILTER
FILTER
AUX
PILOT PROCESSOR
PILOT SELECTOR
RAKE WEIGHT COMPUTER
DEMUX
2:1
DECODE
MODE DETECTOR
CHANNEL MEASUREMENT & FEEDBACK PROCESSOR

FIG. 1

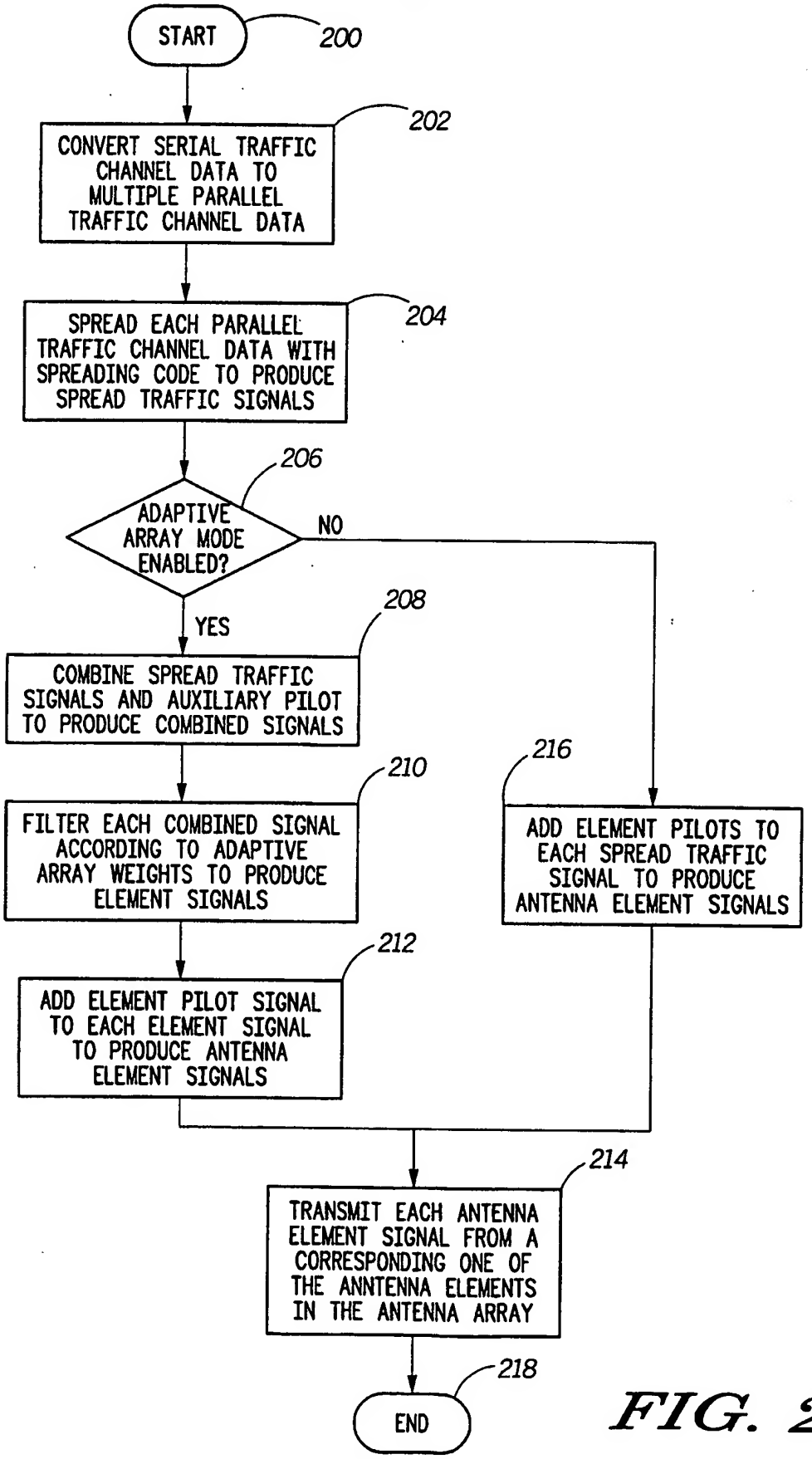

START
200
CONVERT SERIAL TRAFFIC CHANNEL DATA TO MULTIPLE PARALLEL TRAFFIC CHANNEL DATA
202
SPREAD EACH PARALLEL TRAFFIC CHANNEL DATA WITH SPREADING CODE TO PRODUCE SPREAD TRAFFIC SIGNALS
204
ADAPTIVE ARRAY MODE ENABLED?
206
NO
YES
COMBINE SPREAD TRAFFIC SIGNALS AND AUXILIARY PILOT TO PRODUCE COMBINED SIGNALS
208
FILTER EACH COMBINED SIGNAL ACCORDING TO ADAPTIVE ARRAY WEIGHTS TO PRODUCE ELEMENT SIGNALS
210
ADD ELEMENT PILOT SIGNAL TO EACH ELEMENT SIGNAL TO PRODUCE ANTENNA ELEMENT SIGNALS
212
ADD ELEMENT PILOTS TO EACH SPREAD TRAFFIC SIGNAL TO PRODUCE ANTENNA ELEMENT SIGNALS
216
TRANSMIT EACH ANTENNA ELEMENT SIGNAL FROM A CORRESPONDING ONE OF THE ANNTENNA ELEMENTS IN THE ANTENNA ARRAY
214
END
218

FIG. 2

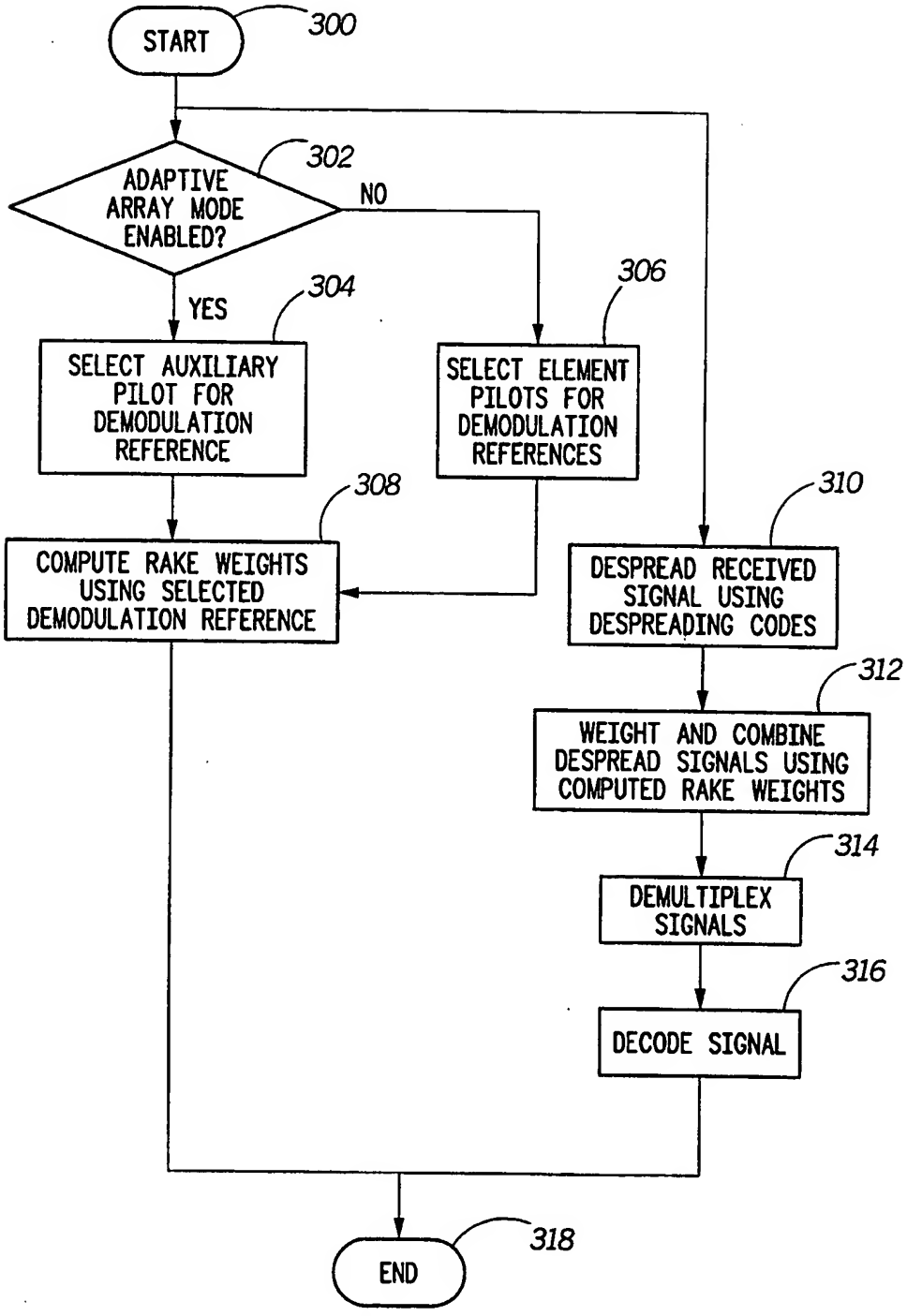

START
300
ADAPTIVE ARRAY MODE ENABLED?
302
NO
YES
304
306
SELECT AUXILIARY PILOT FOR DEMODULATION REFERENCE
SELECT ELEMENT PILOTS FOR DEMODULATION REFERENCES
308
310
COMPUTE RAKE WEIGHTS USING SELECTED DEMODULATION REFERENCE
DESPREAD RECEIVED SIGNAL USING DESPREADING CODES
312
WEIGHT AND COMBINE DESPREAD SIGNALS USING COMPUTED RAKE WEIGHTS
314
DEMULTIPLEX SIGNALS
316
DECODE SIGNAL
318
END

FIG. 3

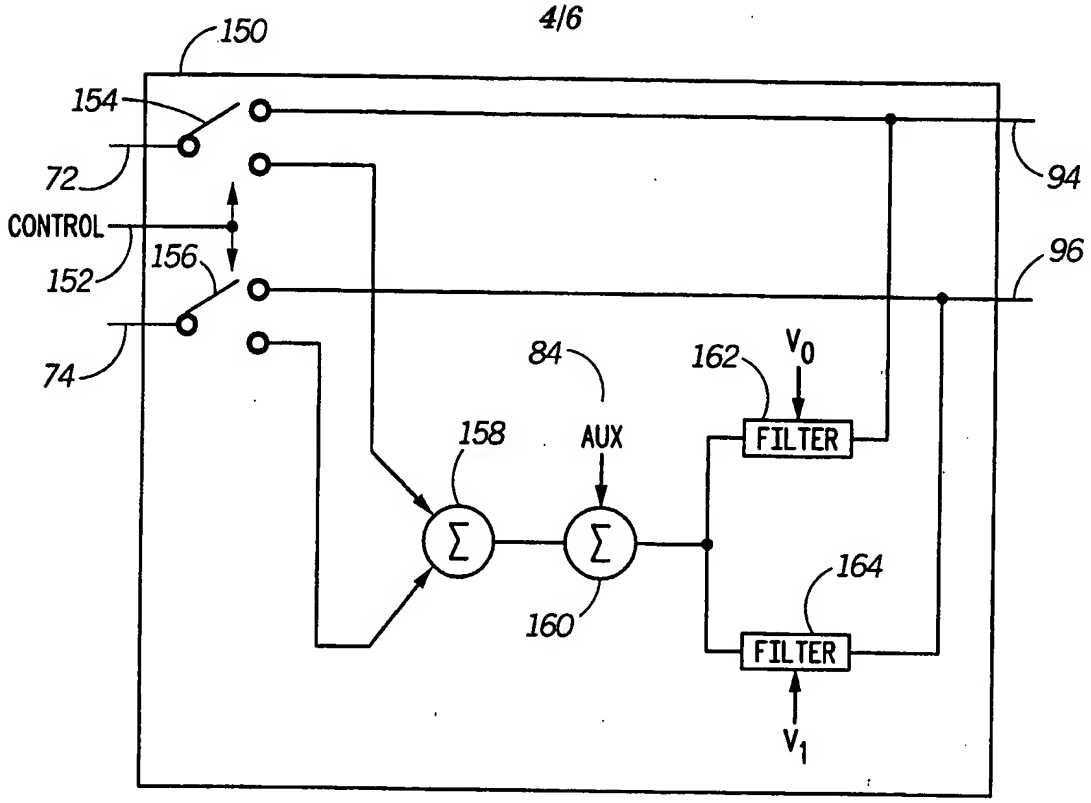

150
154
72
CONTROL
152
156
74
94
96
84
AUX
158
160
162
V_0
FILTER
164
FILTER
V_1

FIG. 4

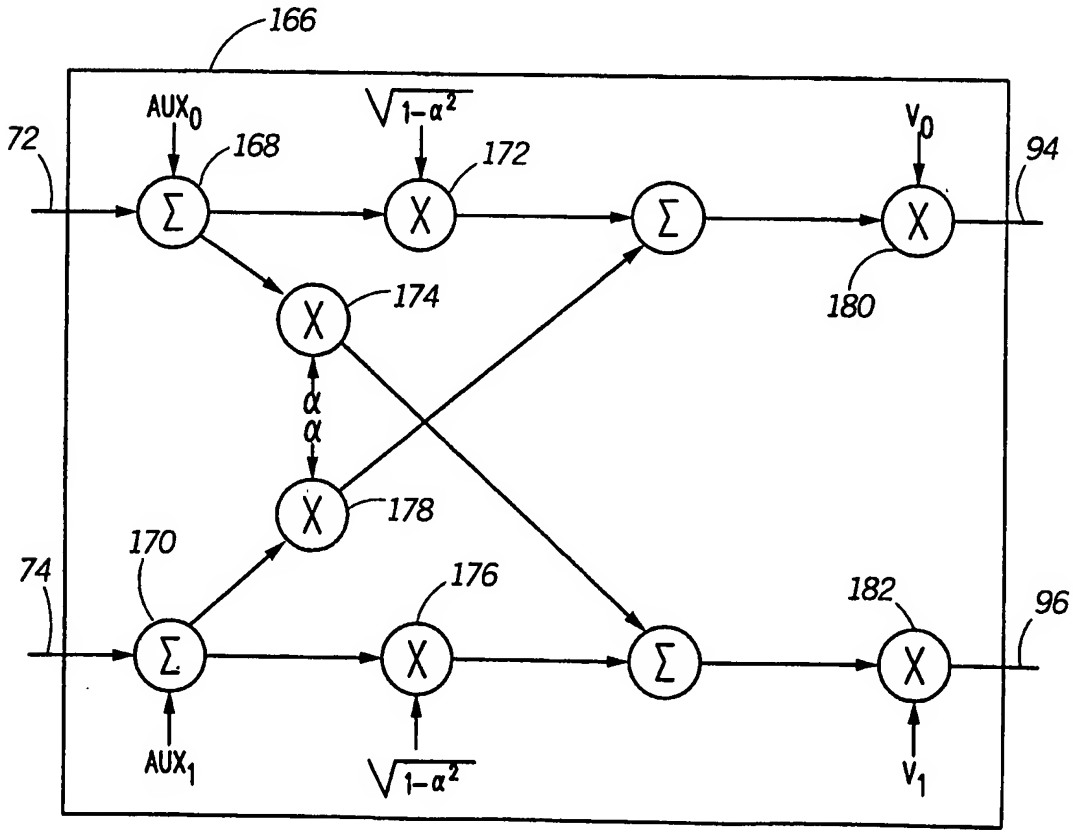
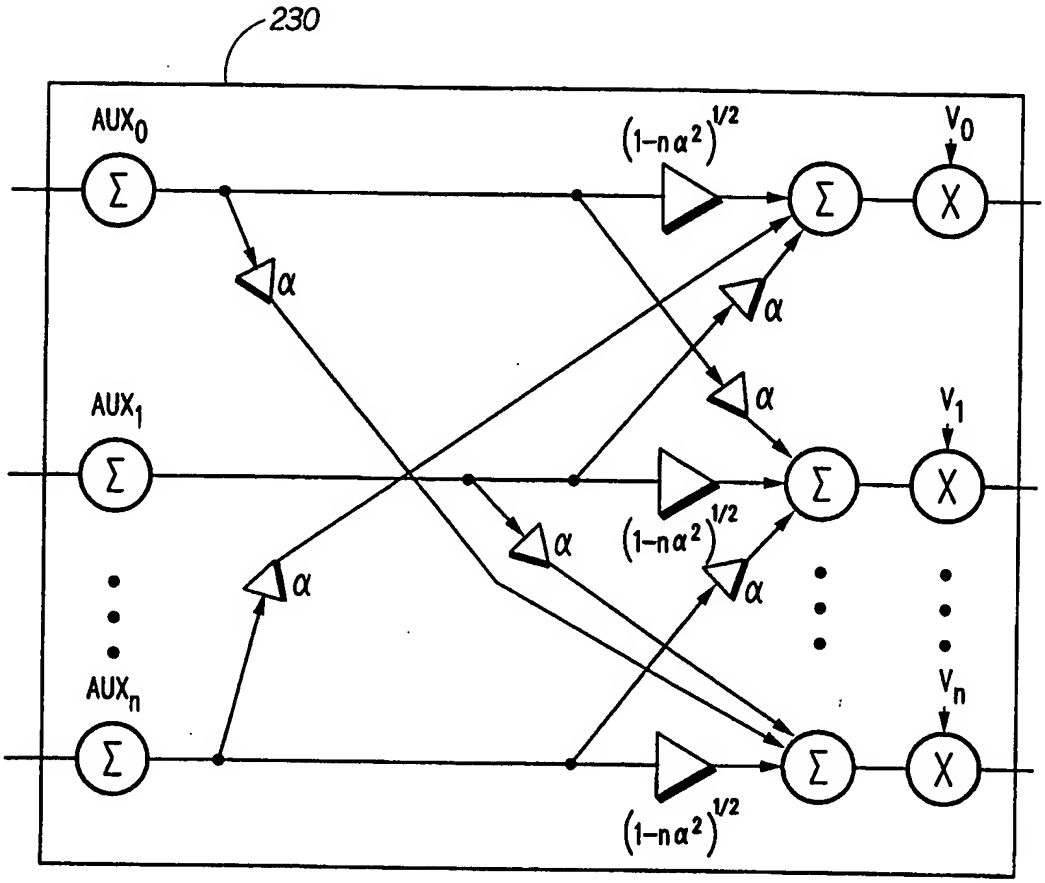

166
AUX_0
72
168
$\sqrt{1-\alpha^2}$
172
V_0
94
174
180
α
α
178
170
74
176
182
96
AUX_1
$\sqrt{1-\alpha^2}$
V_1

FIG. 5



$$0 \leq \alpha \leq \frac{1}{\sqrt{n+1}}$$

FIG. 6

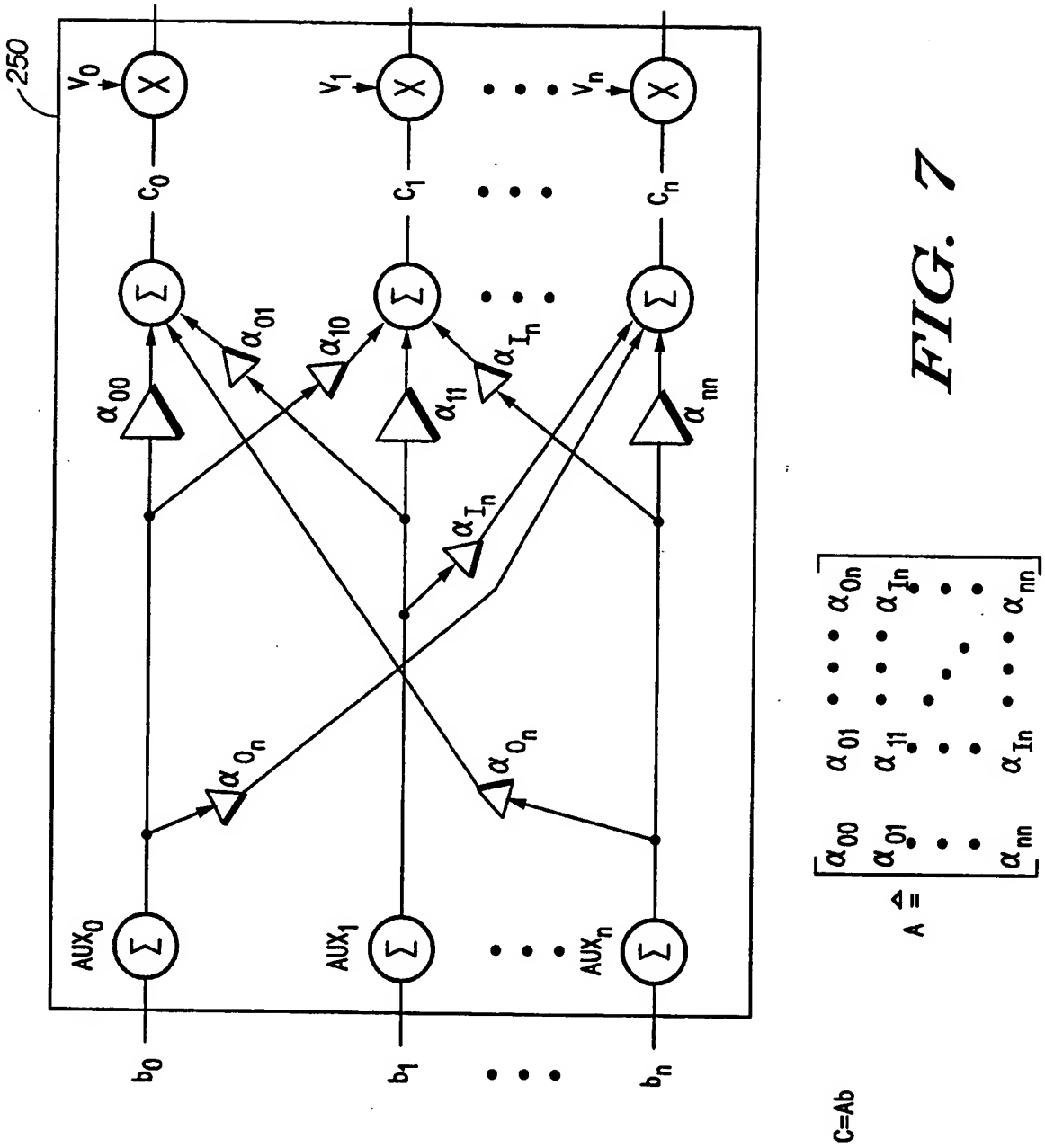

250
v_0
v_1
v_n
c_0
c_1
c_n
α_{00}
α_{01}
α_{10}
α_{11}
α_{In}
α_{nn}
α_{On}
AUX_0
AUX_1
AUX_n
b_0
b_1
b_n
C=Ab
A =

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/23266

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 01/69
US CL :375/130

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/130, 140, 141,146,147

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST
orthogonal, diversity,adaptive array,adaptive antenna arrays.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 5,956,368 A (JAMAL et al) 21 September 1999, col.5, line 64-col.7, line 55.	1-2,5,7,9
X	US 5,764,690 A (BLANCHARD) 09 June 1998, col. 2, lines 41-57; col. 3, lines 9-56; col. 5, lines 3-22.	11
X	US 5,623,485 A (BI) 22 April 1997, see figs. 2-4.	10-11
A	US 5,467,367 A (IZUMI et al) 14 November 1995, see fig.2.	1-9
A	US 5,028,931 A (WARD) 02 July 1991, absract.	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 19 NOVEMBER 1999	Date of mailing of the international search report 09 DEC 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer TEMESGHEN GHEBRETINSAE P. Matthews Telephone No. (703) 305-4777

Form PCT/ISA/210 (second sheet)(July 1992)*